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JHRP-78/1

Interim Report

MAINTENANCE METHODS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Stanley J. Virkler

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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Interim Report

MAINTENANCE METHODS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

February 28, 1978

File: 6-20-11

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-52K

The attached Interim Report is submitted on the JHRP Research Study entitled "Maintenance Methods for Continuously Reinforced Concrete Pavements". The report has been authored by Mr. Stanley J. Virkler under the direction of Professors E. J. Yoder and Donn E. Hancher.

This research is a cooperative venture in which the Indiana State Highway Comm ission as well as the Federal Highway Administration participated in planning the research. The construction plans were prepared by the Indiana State Highway Commission under the supervision of Mr. S. R. Yoder. Construction was carried out on a test pavement on I-65 south of Indianapolis. The first interim report authored by Mr. Robert Florence summarized the construction of the test pavements. Upon completion of the construction of the test pavements, Professor Hancher joined the research team to assist in analysis of the data, particularly from the economic point of view.

This report includes the first evaluation of data that have been obtained on performance of the pavements over the past two years. The data include those obtained in the Fall months of 1977 and include a general analysis of the performance of the pavements during the period of time from its construction in 1974 to the end of 1977. This report gives recommendations relative to the suitability of the various methods that have been used for maintaining this type of pavement. Cost data are presented which indicate the viability of some of the methods tried; the failures of other methods are discussed as well.

An additional condition survey was made in the spring of 1978. Deflection measurements were also made at several selected locations.

A Final Report will be prepared in early FY 79 in which recommendations will be made relative to the best type of maintenance to be used for continuously reinforced concrete pavements.

Respectfully submitted,

Harold L. Michael

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Interim Report

MAINTENANCE METHODS FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

by

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Project No.: C-36-52K

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Conducted by

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Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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16. Abstract
In late 1974, test maintenance sections were constructed on a section of I-65 south of Indianapolis, Indiana. The road was stratified into "similar" sections of pavement using deflection, cracking, and breakup as selection criteria. Various types of measures including concrete shoulders, undersealing, asphalt overlay, and installation of drains with various combinations of these methods were applied as a means for strengthening the pavements. In each case the pavement was patched prior to the installation of the maintenance technique.

Since its construction, performance surveys have been made each spring and fall using deflection measurements, crack counts and a general condition survey of the test pavements. Soil samples that were obtained during the construction were tested and the soil and subbase characteristics were evaluated. A cost analysis was performed with a time frame of two years and an estimated cost for a third year of maintenance of the pavements.

The overlay methods exhibited good behavior over the two years of service. The subdrains and concrete shoulder methods produced less than expected performance.

The project is scheduled for completion in June 1979. A final report will be submitted during FY 78-79.

17. Key Words
CRC Pavements; Maintenance; Overlays; Concrete Shoulders: Maintenance of CRC Pavements

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The author is appreciative to Professor Donn Hancher for his contributions to the project, and for his review of this report. Thanks is also extended for his guidance and counselling of my academic education at Purdue University.

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Recognition should be made of the cooperation and time spent by the Research and Training Center along with the ISHC. Those who were instrumental in the success of the

deflection testing were Fred Chuck, Steve McClain, Keith Corban, and Mike Hoffman.

Appreciation is also due to those who helped in the typing and drafting of this manuscript, especially Sandy Storz, Nancy Warren, and Kamy Pirzadeh. The author remembers Kurt Bahler and Gordy Gerber for proofreading the text. Professor Scholer also spent time reviewing the manuscript and he should be thanked.

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TABLE OF CONTENTS

Page

LIST OF TABLES vii

LIST OF FIGURES. x

HIGHLIGHT SUMMARY. xiii

INTRODUCTION 1

HISTORY OF RESEARCH ON CRCP IN INDIANA 2

SIGNIFICANT FACTORS INFLUENCING PERFORMANCE. 3

PURPOSE OF THIS RESEARCH 4

PROCEDURE FOR SELECTION OF TEST SECTION. 5

Selection of Test Sections within the Test Pavement 7

MAINTENANCE METHODS USED 8

Concrete Shoulders 8
Subdrains. 10
Undersealing 13
Asphalt Concrete Overlay 14
Concrete Patching. 14
Full Depth Bituminous Patching 15

PERFORMANCE SURVEYS. 16

Special Deflection Measurements. 17

RESULTS OF PERFORMANCE SURVEYS 18

Failures 18
Failures Adjacent to Patches 18
Failures in the Concrete Shoulder Sections . . . 22
Progression of Failures with Time. 24
Results of Failure Surveys 26
Deflection Measurements. 28
Deflection as a Function of Season of Year . . . 29
Comparison of Deflections of Various
Maintenance Sections. 29

TABLE OF CONTENTS (Continued)

Page

Procedure 30
Method and Layout 30
Analysis 31
Deflection For the Various Maintenance Methods 35
Statistical Analysis of Overlay Thickness . . . 39
Procedure 40
Model 40
Analysis 41
Conclusion, Deflection and Overlay Thickness 42
Effect of Concrete Shoulder on Deflection . . . 42
Deflection Measurements at Failures and Patches 47
Crack Analysis 47
Results 49

COST ANALYSIS 52

Conclusion 53

EVALUATION OF MAINTENANCE METHODS 55

Underseal and Overlay 55
Asphalt Overlay 55
Overlay and Subdrains 56
Undersealing 57
Bituminous Patches 58
Concrete Patching Only (Control Sections) . . . 59
Subdrains 60
Concrete Shoulders 61
Subdrain and Concrete Shoulders 62

SUMMARY AND RECOMMENDATIONS 64

Summary of Performance 65
Summary Discussion 68

RECOMMENDATIONS FOR FUTURE STUDY 69

REFERENCES 70

APPENDICES

Appendix A: Physical Test Data on Subbase and Subgrade Samples 72

TABLE OF CONTENTS (Continued)

Page

Appendix B: Number of Failures in Test Sections and Approximate Dates of Occurrence. 77
Appendix C: Deflection of Test Sections at Various Times. 92
Appendix D: Deflection of Pavements with Concrete Shoulder. 108
Appendix E: Typical Deflection Data Taken at Failures and Patches 112
Appendix F: Cost Data 122

LIST OF TABLES

Table Page

1 Failures per Section 20

2 Failures per Section 21

3 Failures as a Function of Time 25

4 Failures per Maintenance Method. 27

5 Anova, Deflection of Maintenance Sections with Time 33

6 Cell Means of Deflection for Maintenance Methods over Time. 36

7 Percent Change in Deflection over Time 38

8 Anova, Effect of Overlay Thickness 43

9 Lineal Feet of Closely Spaced Cracks per 100 Feet 50

10 Lineal Feet of Closely Spaced Cracks per 100 Feet 51

11 Total Cost Breakdown 54

Appendix Table

A1 Sieve Analysis of Subgrade Samples 73

A2 Test Results for Subgrade Samples. 74

A3 Sieve Analysis of Subbase Samples. 75

A4 Test Results for Subbase Samples 76

B1 Failures Associated with Patches 77

B2 Failures Associated with Patches 78

B3 Failures Associated with Patches 79

LIST OF TABLES (Continued)

Appendix Table — Page

B4 Failures Associated with Patches 80

B5 Failures in CRCP with Concrete Shoulder. 81

C1 Deflection Measurements. 92

C2 Deflection Measurements. 93

D1 Deflection Measurement Means for Concrete Shoulder Sections. 108

D2 Deflection Measurement Means for Concrete Shoulder Sections. 109

D3 Deflection Measurement Means for Concrete Shoulder Sections. 110

D4 Deflection Measurement Means for Concrete Shoulder Sections. 111

F1 Cost of Section "A". 122

F2 Cost of Section "B". 123

F3 Cost of Section "D". 124

F4 Cost of Section "E". 125

F5 Cost of Section "F". 126

F6 Cost of Section "G". 127

F7 Cost of Section "H". 128

F8 Cost of Section "I". 129

F9 Cost of Section "J". 130

F10 Cost of Section "K". 131

F11 Cost of Section "L". 132

F12 Cost of Section "M". 133

F13 Cost of Section "N". 134

LIST OF TABLES (Continued)

Appendix
Table Page

F14 Cost of Section "P". 135

F15 Cost of Section "Q". 136

F16 Cost of Section "S". 137

F17 Cost of Section "T". 138

F18 Cost of Section "V". 139

F19 Cost of Section "W". 140

F20 Cost of Section "X". 141

F21 Cost of Section "Y". 142

F22 Cost of Section "Z". 143

F23 Cost of Section "AA" 144

F24 Cost of Section "BB" 145

F25 Cost of Section "CC" 146

F26 Cost of Section "DD" 147

F27 Cost of Section "EE" 148

F28 Cost of Section "GG" 149

F29 Cost of Section "HH" 150

LIST OF FIGURES

Figure Page

1 As Built Maintenance Sections. 9

2 Layout of Concrete Shoulders 11

3 Layout of Tie Bars for Concrete Shoulders. . . . 12

4 As Built Maintenance Sections. 19

5 Mean Deflection vs. Time 34

6 Mean Deflection vs. Time, Combination of Overlay Sections 44

7 Layout of Statistical Model for Concrete Shoulders. 46

8 Typical Crack Patterns 48

Appendix Figure

B6 Number of Failures Observed, Underseal and Overlay. 82

B7 Number of Failures Observed, Overlay 83

B8 Number of Failures Observed, Overlay and Subdrains. 84

B9 Number of Failures Observed, Underseal 85

B10 Number of Failures Observed, Bituminous Patching 86

[illegible]

B12 Number of Failures Observed, Concrete Patching . 88

B13 Number of Failures Observed, Subdrains 89

B14 Number of Failures Observed, Concrete Shoulder . 90

B15 Number of Failures Observed, Subdrains and Concrete Shoulders 91

LIST OF FIGURES (Continued)

Appendix Figure		Page
C3	Mean Deflection vs. Time, Underseal and Overlay .	94
C4	Mean Deflection vs. Time, Overlay	95
C5	Mean Deflection vs. Time, Overlay and Subdrains .	96
C6	Mean Deflection vs. Time, Underseal	97
C7	Mean Deflection vs. Time, Bituminous Patching . .	98
C8	Mean Deflection vs. Time, No Maintenance.	99
C9	Mean Deflection vs. Time, Concrete Patching . . .	100
C10	Mean Deflection vs. Time, Subdrains	101
C11	Mean Deflection vs. Time, Concrete Shoulder . . .	102
C12	Mean Deflection vs. Time, Subdrains and Concrete Shoulders	103
C13	Mean Deflection vs. Time, 2" Overlay Section. . .	104
C14	Mean Deflection vs. Time, 3" Overlay Section (I).	105
C15	Mean Deflection vs. Time, 3" Overlay Section (II)	106
C16	Mean Deflection vs. Time, 5" Overlay Section. . .	107
E1	Deflection in Vicinity of Concrete Patch.	112
E2	Deflection in Vicinity of Concrete Patch.	113
E3	Deflection in Vicinity of Concrete Patch.	114
E4	Deflection in Vicinity of Concrete Patch.	115
E5	Deflection in Vicinity of Concrete Patch.	116
E6	Deflection in Vicinity of Concrete Patch.	117
E7	Deflection in Vicinity of Concrete Patch.	118
E8	Deflection in Vicinity of Concrete Patch.	119

LIST OF FIGURES (Continued)

Appendix Figure — Page

E9 Deflection in Vicinity of Concrete Patch. 120

E10 Deflection in Vicinity of Concrete Patch. 121

HIGHLIGHT SUMMARY

A substantial amount of continuously reinforced concrete pavement has been constructed in recent years in Indiana. A considerable amount of these pavements have shown some distress. Past research by Faiz and Yoder have delved into the causes of this distress, and research by Florence was instrumental in setting up a construction test section.

This research deals with the observation of performance within the test section designed by Florence. Ten maintenance methods were constructed (2 being control methods) under Florence's criteria.

The performance of each method was measured by taking deflection measurements, by observing the number of failures in each maintenance method, and observing crack patterns. Twenty-five soil samples were tested to observe the soil characteristics within the subbase and subgrade. A cost breakdown was performed with a time frame of two years, and a third year with estimated costs.

The three overlay methods exhibited good behavior over the two years of being in service, although it is difficult to predict future behavior. The subdrains, concrete shoulder,

and concrete patching methods produced less than expected performance, The present method of construction should be reviewed to improve performance.

This report's conclusions were made over a time period of only 2 years, and therefore definite conclusions cannot be made at this time. However, the data shows definite trends that should be beneficial to the state.

INTRODUCTION

The Indiana State Highway Commission (ISHC) has constructed 695.5 two-lane miles of continuously reinforced concrete pavement (CRCP) during the past 11 years. The majority of these pavements have been constructed on the Interstate System.

In some cases, a large portion of these pavements have shown failures and distress at certain locations. The Joint Highway Research Project (JHRP) was asked to conduct research into the causes of this distress (see References 2-4, 6, and 8-12)*. In the summer of 1975, construction of several maintenance sections were completed on I-65 south of Indianapolis. This work was reported by R. H. Florence, Jr. (5).

This research deals with analyzing the maintenance sections which were summarized by 10 maintenance methods. The criteria used in the analysis are deflection, cracking, and breakups. The maintenance methods were also analyzed by determining the most cost effective method.

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*Numbers in parenthesis refer to bibliography at the end of this report

HISTORY OF RESEARCH ON CRCP IN INDIANA

Purdue University was first contacted in July 1972 regarding the problem of distress in CRCP, at which time plans were made for a long-range research project. Recommendations were made regarding design changes that would lead to improved performance of CRCP.

Since 1972, the research has followed a sequential process wherein the present maintenance project has evolved. The list given below is a very brief summary of the overall approach that was taken:

1. Detailed study of performance on I-65. This was conducted during the summer months of 1972.
2. Statewide performance survey of all CRC pavements in Indiana. This part of the study was conducted in late fall of 1972.
3. Detailed study of selected pavements including field measurements. This portion of the study was conducted in early summer 1973.
4. Laboratory evaluation of materials obtained in step 3 above. This phase of the study was completed in January 1975.
5. Analysis of factors influencing performance. This phase of the study was completed in summer of 1975.
6. Construction of the test sections on I-65 which included 10 maintenance methods.

SIGNIFICANT FACTORS INFLUENCING PERFORMANCE

The factors influencing the performance of CRCP included (1) subbase type and degree of compaction, (2) type of steel fabrication, (3) an interaction of steel placement methods and construction, and (4) traffic. These factors have been discussed in detail in previous reports (2-4, 11). Of these, the first factor (subbase) is the prime contributor to distress. On the other hand, most distress has been attributed to a combination of the above factors.

Pumping has occured on pavements which have shown the greatest amount of distress. It was revealed that most of the pumping occurred on gravel subbases, while crushed stone and slag subbases showed good performance. It was also found that the gravel subbases were not sufficiently compacted and had relatively low permeability and strength.

The design temperature drop used in the computations was $100^{\circ}F$, although Indiana experiences temperature drops greater than $125^{\circ}F$. This suggests that the design 0.6 percent steel is marginally low for Indiana conditions. It was shown that a major contributor to failures occurring on continuously reinforced concrete pavements in Indiana can be associated with use of pre-set steel set on chairs. The poorest performance has been shown when bar mats were used.

PURPOSE OF THIS RESEARCH

Since a significant amount of the continuously reinforced pavements in Indiana have shown some degree of distress, it was considered desirable by engineers from the Indiana State Highway Commission to investigate various methods of maintaining the pavements presently in existence. It was the purpose of this research project to select a pavement which contained a large portion of the significant factors which have been shown to contribute to poor performance of CRCP in Indiana, and to investigate various techniques for maintaining this pavement. Hopefully, data from this study can be used by the Indiana State Highway Commission for planning maintenance techniques for continuously reinforced concrete pavements on the highway system in Indiana.

At the outset, it was recognized that it would be necessary to restrict this study to a relative short section of pavement. Hence, the scope of the study involved construction of various maintenance techniques on a specific section of I-65 south of Indianapolis. Details of the maintenance methods investigated have been presented by Florence (5). The reader is referred to this report for details of the maintenance methods that were adopted.

PROCEDURE FOR SELECTION OF TEST SECTION

As was mentioned previously, several factors have been shown to be significant contributors to performance of CRCP in Indiana. These include subbase type and degree of compaction of the subbase, type of steel fabrication (notably use of bar mats), an interaction of steel placement methods and construction, and traffic. Therefore the major consideration used in selecting the test pavement was to use a pavement that had the following features:

1. Subbase of poor quality
2. Bar mat construction
3. Heavy truck traffic
4. A significant number of failures on the test pavement prior to the experiment.

In addition, it was desirable to keep the test pavement as close to Indianapolis and to Purdue University as possible to facilitate travel to and from the experiment. As a result, a section of pavement of I-65 south of Indianapolis between the Greenwood and Franklin interchanges was selected for study. This pavement carries at the present time 23,450 ADT, and was constructed using bar mats on a gravel subbase known to be impervious. This test pavement is in the Seymour district of the Indiana State Highway Commission.

This test pavement is on relatively flat terrain, and the underlying soils are Wisconsin Drift. The results of

physical tests made on samples of the subgrade are shown on Tables A1 to A4 in Appendix A.

The soils at the site are relatively coarse grained and have low plasticity. In some cases the materials are non-plastic and contain little material passing the No. 200 mesh sieve.

Along with the relatively granular nature of the underlying soil, the area is flat and has a high water table, especially in the spring months of the year. The area in general has poor internal drainage because of the high water table and the flat topography. The flat topography accompanied by the high water table has no doubt contributed in part to the performance of the test pavement prior to installation of the maintenance sections.

It is pointed out that subgrade and environmental factors surrounding the pavement were not considered when selecting the test pavement per se. Nevertheless, it can be stated that the subgrade at the test pavement and the surrounding environment is typical of a large region of Indiana covered with Wisconsin Drift and, incidently, where many of the distress manifestations have been noted on continuously reinforced concrete pavement. Therefore, it is felt that the site of the test pavement is representative of a large number of mileage of CRC pavements in Indiana that has shown some distress.

Selection of Test Sections within the Test Pavement

Florence (5) discussed in detail the techniques used for selecting the various test sections on the test pavement.

Crack width, deflection, and number of breakups has been the criteria used for indicators of poor pavement condition (12). Previous studies (2-4, 6, and 8-12) have suggested 0.9 mils (10^{-3} inches)[*], as measured by the Dynaflect, may indicate poor performance. Deflection readings were taken at 25' intervals over the study area.

Sections of pavement were analyzed and a rating number from 1-12 was assigned (see Florence, 5). The layout of study sections of a given maintenance type was governed by four criteria:

1. It was desirable to make a section of one type of maintenance as long as possible;
2. At least one "control section" was retained for each rating number 1-12;
3. As many different types of maintenance methods as possible were used for each rating number;
4. Allocation of the maintenance to be used to each rating number , with the fewest actual sections of that rating, was done first.

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[*] The term mil as used herein is deflection in 1/1000 inch units

MAINTENANCE METHODS USED

The basic premise upon which the maintenance methods were based was, "What methods can be used to correct the known deficiencies in the existing pavement?" It was known that deflections of the pavement were higher than desirable, drainage of the subbase was questionable and pumping had existed on the pavement, and that in all probability some void spaces existed under the pavement at the time of the study. Therefore, using the deflection measurements and performance surveys discussed in previous paragraphs, tentative test sections were laid out.

The next step was to discuss potential maintenance to correct the known defects in a group discussion. This group included personnel from Purdue University, the Indiana State Highway Commission and Federal Highway Administration. From these discussions tentative methods of maintaining the pavement were selected and the test sections were laid out using the technique previously presented.

The six major maintenance types are discussed in subsequent paragraphs. A layout of the test section is shown in Figure 1.

Concrete Shoulders

Concrete shoulders tied to the existing pavement, serve to stiffen the existing pavement and thereby decrease the

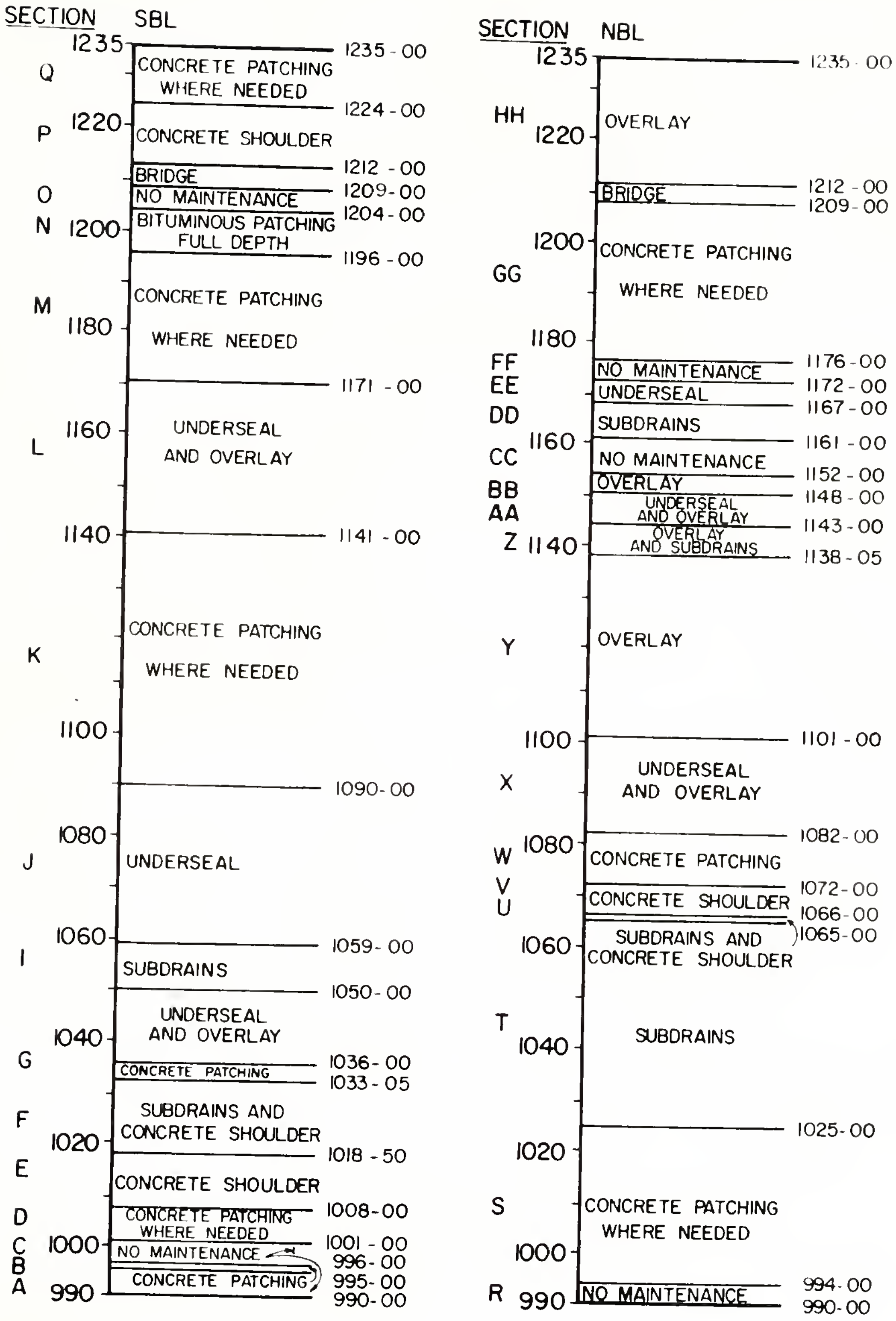


FIGURE 1. AS BUILT MAINTENCE SECTIONS

NOTE CONCRETE PATCHING WAS DONE WHERE NEEDED IN ALL AREAS EXCEPT NO MAINTENANCE AREAS.

deflection and consequent pumping and failure of the pavement. Concrete shoulders were constructed with contraction joints spaced at 15 foot intervals. They were tied to the existing pavement with 30 inch long No. 4 tie bars. The tie bars were spaced at three different intervals (12"c-c, 24"c-c, and 30"c-c) at specific locations within the project as shown in Figures 2 and 3.

There were two general observations that should be noted here. The first, every other joint in the concrete shoulder cracked after about five days. Second, small amount of honeycobing was noticed at the outside edge of the concrete shoulder in some locations.

Subdrains

The use of subdrains was an obvious type of maintenance, because pumping of the pavement due to free water on top of the subbase is believed to be a major cause of distress. In order to remove the water from the top of the subbase as quickly as possible, subdrains were installed directly adjacent to the pavement edge. Installation of the subdrains required the complete removal of a trench through the shoulder, subbase, and subgrade to a depth of 42", where the drain pipe was placed. The trench was then filled with No. 7 permeable gravel.

Two general observations should be noted at this stage. Several days after the subdrains had been installed, water was noticed draining from them. Second, the subdrains are deeper than the minimum necessary for drainage of the

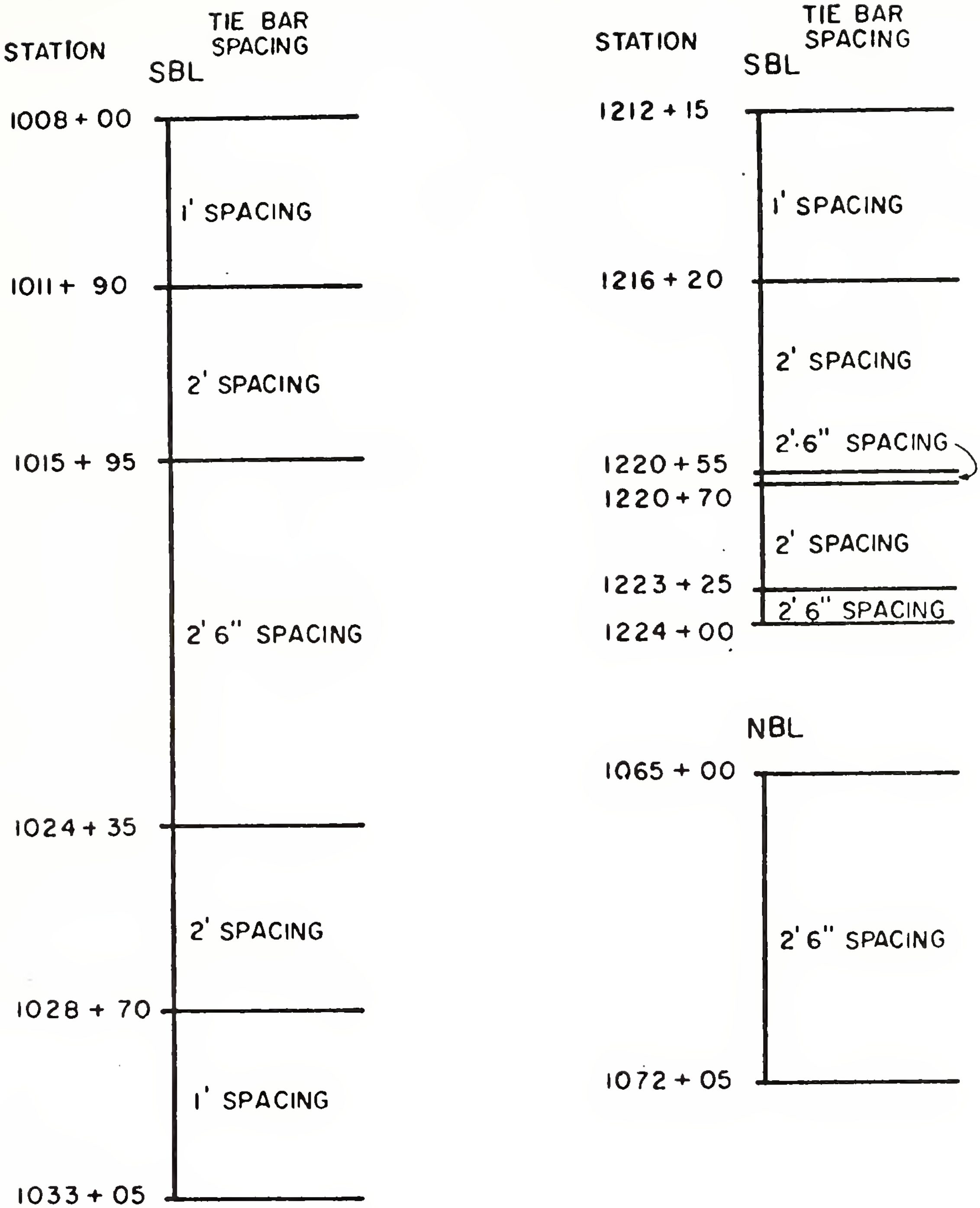


FIGURE 2. LAYOUT OF CONCRETE SHOULDERS

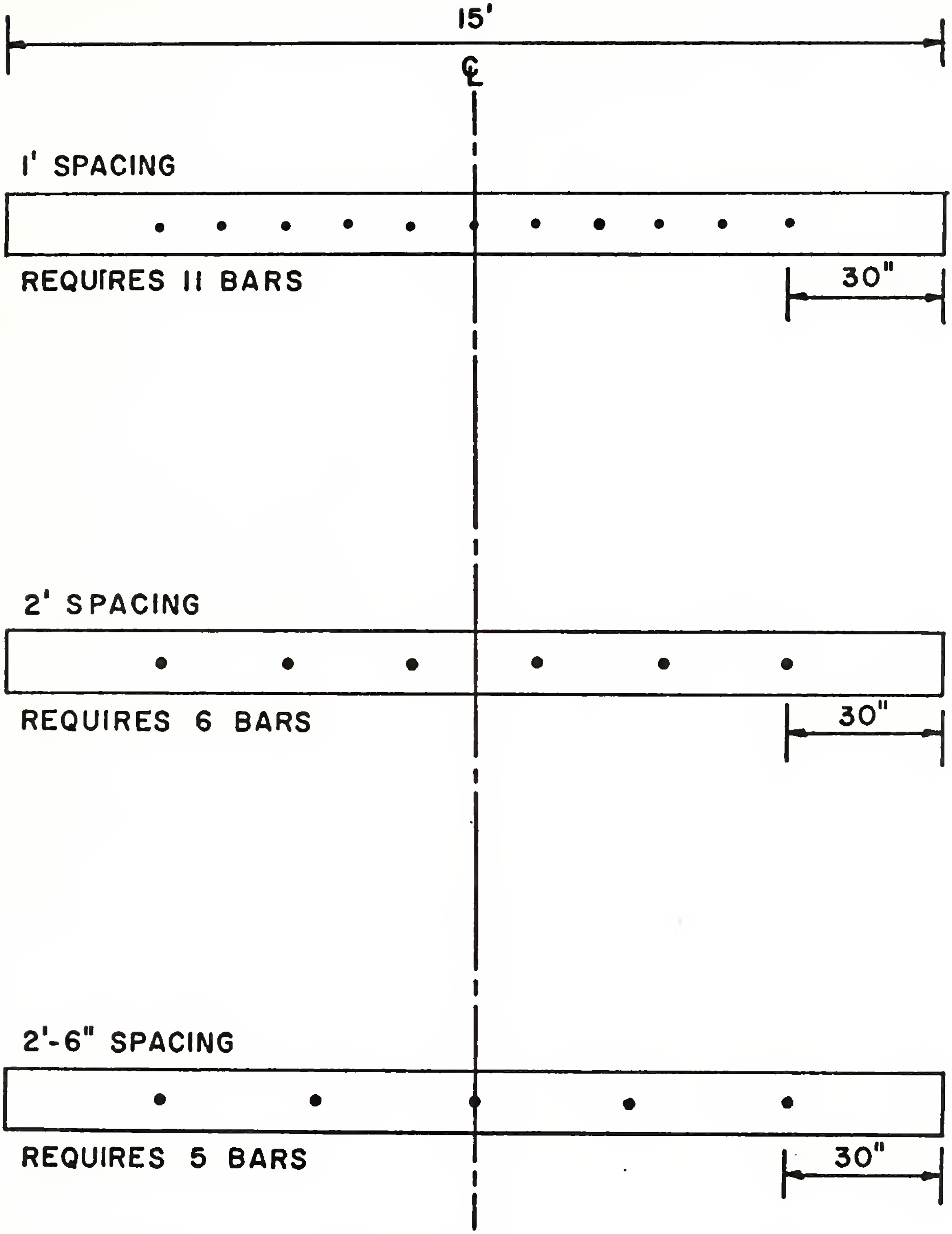


FIGURE 3. LAYOUT OF TIE BARS FOR CONCRETE SHOULDERS

subbase alone and hence, they are no doubt removing some groundwater as well as water from the subbase.

Undersealing

Undersealing and mudjacking have been used as a means of filling cavities under a concrete pavement and is accomplished by pumping hot asphalt under the pavement. The asphalt also forms a waterproof layer that assists in prevention of continued erosion of the subbase due to pumping.

Two inch holes were drilled through the pavement (right hand lane), and hot asphalt was then pumped through the hole until either the pavement or the shoulder lifted approximately 1/8"-1/4". In general, one row of holes spaced 8'c-c were used where deflections were greater than 0.9 mils, and no undersealing was necessary where deflections were less than 0.9 mils. In the southbound lane from stations 1171+00-1141+00, two rows staggered every four feet was used with close crack spacing and high deflections, but this criteria was not used in the remainder of the project.

General observations with undersealing method are listed below:

1. The asphalt at times found a weak spot in the shoulder and would raise it and pour out onto the shoulder and pavement.
2. The contractor had difficulty with the pump on the third and last day of undersealing because it didn't seem to be pumping under enough pressure.

3. The quantities of asphalt pumped under the pavement indicated there were large voids under the pavement. When the pavement was cut to be patched at station 1088+20 SBL, the undersealing was found to be continuous throughout the patch and ranged in thickness from 1/8" to 3/8".

Asphalt Concrete Overlay

On this project, the overlay was intended to improve the structural adequacy of the existing CRC pavement and to reduce deflection. Thickness of overlay was a major variable in this method because it was not known if the high deflection of CRC pavements would permit the use of thin overlays. A bituminous base 3 inches thick was used on all sections except on the northbound lane between stations 1082+00-1152+00 where the overlay thicknesses shown below were used. A 70 lb per sq. yd. anti-skid surface was applied on the entire overlay.

NBL 1082+00-1110+00	2" overlay
NBL 1110+00-1119+00	3" overlay
NBL 1119+00-1129+00	5" overlay
NBL 1129+00-1152+00	3" overlay

Concrete Patching

Concrete patching was required in all sections for the permanent repair of isolated locations of structurally damaged or failed areas. The policy set forth required that patching should be done on all breakups in addition to any other Maintenance that was used. There were also "No Maintenance" control sections with no patching.

Control sections (maintained with concrete patches only) were planned for each of the maintenance sections. In addition, several "no maintenance" sections existed at the site. These later sections were in excellent condition prior to the test, and by and large, are still performing satisfactory, although some minor patching was necessary during the second year.

Concrete patching was started by making four transverse cuts. The two inside cuts were through the concrete while the other two, which were 3 feet outside of the first two, were only cut to the steel. The concrete was then broken out and removed. The hole was backfilled, compacted and leveled, while steel reinforcing was tied to the existing steel. Concrete was then poured and vibrated in place. French drains were also placed at every patch to allow for quick drainage of the patched area.

Full Depth Bituminous Patching

Full depth bituminous patching were used to compare its effectiveness with concrete patching. Only a minimal amount of bituminous patches were used in this contract. The bituminous patches were constructed by cutting the pavement full depth and removing the existing steel. After compacting the subbase the asphalt base was installed with a Type B surface.

PERFORMANCE SURVEYS

The maintenance test sections were completed in the fall months of 1975. Due to climatic conditions it was not possible to place the antiskid surface on the overlay sections during the fall and this was done the following spring. Likewise, some of the ancillary work (painting, etc.) was also completed the following spring.

A complete performance survey including logging of the extent of failures, cracking and measurement of deflection using the Dynaflect was made immediately prior to construction of the test sections. The performance surveys were repeated immediately following construction of the test sections and then were again repeated each spring and fall up to the fall of 1977.

The performance surveys included complete logging of the extent of cracking that had occurred, logging of the failures that took place and measurement of deflection using the Dynaflect at 25 foot intervals. Deflections were made using just the sensor immediately under the vibrating wheels of the Dynaflect.

During each performance survey pictures were taken of each failure for future reference. In addition, pictures were taken of failures at various times of the year whenever the pavement was inspected irrespective of whether it was during the time of the detailed survey or not. The purpose

of recording each of the failures on film was to permit keeping a permanent record of the type of failures that took place and other features which might influence the performance of the pavement such as, "Did the failure occur at a patch?" or "Did the failure occur at a joint on the concrete shoulder?"

Special Deflection Measurements

In addition to the detailed performance surveys which were made each spring and fall, a special program of measuring deflections at areas adjacent to concrete patches was carried out in the spring of 1976. The reason for these special deflection measurements was that it was felt at that time that a relatively large amount of the concrete patches themselves were failing or additional failures were occurring just adjacent to concrete patches. In general, failures that occurred next to concrete patches occurred in the upstream direction of traffic (at the leading edge of the patch as vehicles approached) and there was some question whether or not the original concrete patches were extended far enough in each direction. Figures E1 to E10 in Appendix E show typical data relative to these measurements.

RESULTS OF PERFORMANCE SURVEYS

Failures

An important facet of determining the performance of CRC pavement involves analyzing the number and location of failures (primarily punch outs). The ISHC District personnel determined whether a damaged area was actually a failure or not. This was in accordance with the "ground rules" established at the start of the project. This was done to insure that normal maintenance procedures would be followed. It was considered desirable not to bias the data in any way by having judgments of the research team influence the normal maintenance procedures that are followed by the State.

In the summer of 1975, prior to construction of the test sections, each failure was patched and then the respective maintenance method was performed on each section. In the summer of 1976 each failure found since the 1975 patching was repaired. Data relative to the time of patching, occurrence of failures and locations of failures is shown in Figure 4 and Tables 1-2.

Failures Adjacent to Patches

During the first winter after construction of the test sections, it was found that many patches themselves either failed or failures had occurred ahead of or behind the patch. Therefore, each patch was observed in order to determine the

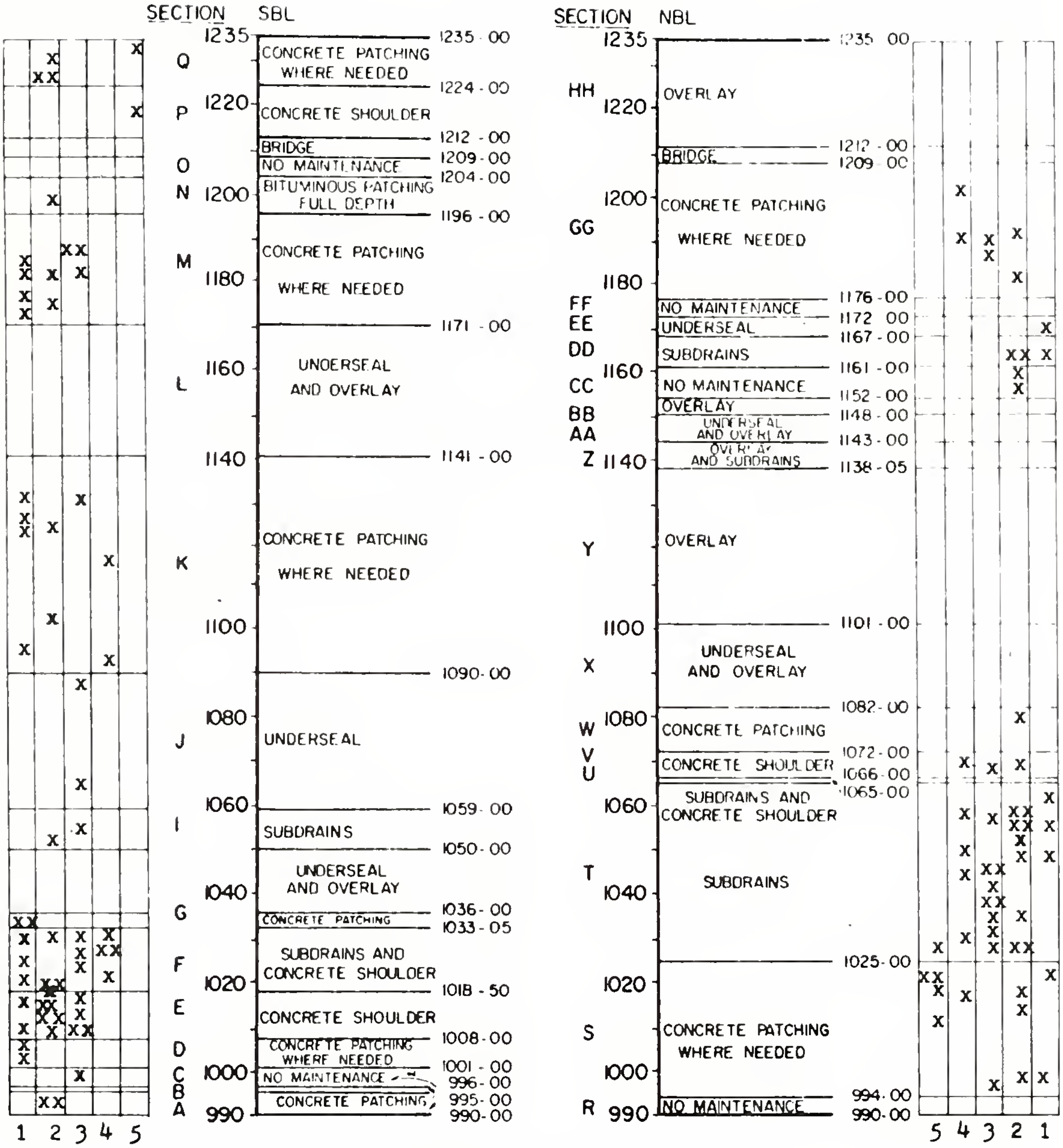


FIGURE 4. AS BUILT MAINTENCE SECTIONS

NOTE CONCRETE PATCHING WAS DONE WHERE NEEDED IN ALL AREAS EXCEPT NO MAINTENANCE AREAS

1. Aug. 75 - March 76
2. March 76 - Aug. 76
3. Aug. 76 - Dec. 76
4. Dec. 76 - July 77
5. July 77 - Oct. 77

SUMMARY OF PATCHING, SBL

STATION	TEST SECTION	LENGTH OF SEC. ft.	NO. OF PATCHES FALL 1976	NO. OF FAILURES FALL 1977
990- 995	No Maintenance	500	2	0
995- 996	Concrete Patching	100	0	0
996-1001	No Maintenance	500	0	1
1001-1008	Concrete Patching	700	2	0
1008-1018+50	Concrete Shoulder	1050	8	4
1018+50-1033	Subdrains and Conc. Shoul.	1450	6	7
1033-1036	Concrete Patching	300	2	0
1036-1050	Underseal and Overlay	1400	0	0
1050-1059	Subdrains	900	1	1
1059-1090	Underseal	3100	0	2
1090-1141	Concrete Patching	5100	6	3
1141-1171	Underseal and Overlay	3000	0	0
1171-1196	Concrete Patching	2500	6	3
1196-1204	Bituminous Patching	800	1	0
1204-1209	No Maintenance	500	0	0
1212-1224	Concrete Shoulder	1200	0	1
1224-1235	Concrete Patching	1100	3	1
	TOTALS	24200	37	23

TABLE I. FAILURES PER SECTION

SUMMARY OF PATCHING, NBL				
STATION	TEST SECTION	LENGTH OF SEC. ft.	NO. OF PATCHES FALL 1976	NO. OF FAILURES FALL 1977
990- 994	No Maintenance	400	0	0
994-1025	Concrete Patching	3100	5	6
1025-1065	Subdrains	4000	11	14
1065-1066	Subdrains & Conc. Should.	100	0	0
1066-1072	Concrete Shoulder	600	1	2
1072-1082	Concrete Patching	1000	1	0
1082-1101	Underseal and Overlay	1900	0	0
1101-1138	Overlay	3700	0	0
1138-1143	Overlay and Subdrains	500	0	0
1143-1148	Underseal and Overlay	500	0	0
1148-1152	Overlay	400	0	0
1152-1161	No Maintenance	900	2	0
1161-1167	Subdrains	600	3	0
1167-1172	Underseal	500	1	0
1172-1176	No Maintenance	400	0	0
1176-1209	Concrete Patching	3300	2	4
1212-1235	Overlay	2300	0	0
	TOTALS	24200	26	26

TABLE 2. FAILURES PER SECTION

percentage of failures associated with patches. This was done for both 1976 and 1977 failures and the results are listed in Tables B1 to B4 in Appendix B.

The results of the special study which determined the association of new failures with old failures is as given below:

Total Failures	112
Isolated Failures	68
Failures at Concrete Patches	43
Failures at Bituminous Patches	1

It is not known at this time whether the high association of new failures with old is due to inadequate patching techniques or some other factor surrounding the pavement (i. e. poor subgrade, inadequate compaction of concrete, etc.). Because of the apparent high incidence of failures adjacent to patches, it was agreed at a meeting in April 1976 that additional deflection measurements should be taken 40 feet before and after the area of every failure. These results, hopefully, would help determine where the patch should begin and end. A deflection greater than 0.9 mils was used as a criteria for patching that area. This point will be discussed further in the section on "Deflection Measurements" in subsequent paragraphs.

Failures in the Concrete Shoulder Sections

Special observation was also made of patches within the sections with concrete shoulders. It was believed after the first winter of performance that more failures were tending

to occur in the continuously reinforced concrete pavement adjacent to the joint in the concrete shoulder than were occurring at mid points between the joints in the concrete shoulder. It was also believed that there were more failures associated with the 12-inch tie bar spacing than the 24-inch and 30-inch tie bar spacing. The results of special surveys on this are shown in Table B5 of Appendix B.

A summary of the 1976 results are as shown below:

Total Failures in Concrete Shoulder Sections	15
Failures in sections with 12-inch tie bar spacing	4
Failures in sections with 24-inch tie bar spacing	6
Failures in sections with 30-inch tie bar spacing	5

As can be seen from the above there is little association with the number of failures that have occurred relative to the spacing of the tie bars in the pavement edge itself. The data would suggest that occurrence of failures bares no relationship with tie bar spacing and therefore greater tie bar spacings may be used on this type of construction. On the other hand, it can be argued that the concrete shoulders themselves were ineffective in preventing additional failures. It should be recalled that this particular section of pavement (primarily at the southern end of the south bound lanes) had shown very poor performance prior to construction of the maintenance sections and hence factors such as subgrade, subbase and others could be major contributors to performance in this situation.

In any event, the concrete shoulders in this particular situation were not considered to be an effective means of preventing additional failures.

Relative to the occurrence of failures adjacent to joints and in midspan the 1976 data are summarized below:

Total number of failures	15
Failures adjacent to joints in the concrete shoulder	8
Failures at mid-span of the concrete shoulder joints	7

On the basis of the above it is to be seen that the occurrence of failures either adjacent to a joint or a mid-span were about evenly distributed.

Progression of Failures with Time

Table 3 shows the number of failures that have occurred on the test pavement during various time periods. Before the test pavements were constructed 102 failures had occurred over the entire section and since that time 112 additional failures have occurred. It should be recalled that this test pavement is considered to be a severe test since it contains most of the features that have been known to contribute to poor performance of CRCP in the state of Indiana.

It is of interest to note that the occurrence of failures bares a relationship with the season of the year. The data show that a large portion of the failures have occurred during the fall-winter-spring months and that the occurrence of failures was reduced over the summer periods. During the cold winter months the pavement is under high tension and likewise this is the period when water accumulations occur.

DATE LOGGED	SEASON	NO. OF FAILURES
Prior to Construction	---	102
September 1975 - March 1976	Winter	24
March 1976 - April 1976	Spring	14
April 1976 - August 1976	Summer	25
August 1976 - December 1976	Fall	29
December 1976 - July 1977	Winter-Spring	13
July 1977 - October 1977	Summer	7
Totals after Construction		112

TABLE 3. FAILURES AS A FUNCTION OF TIME

It is further noted that the progression of failures is decreasing and that the pavement is apparently reaching equilibrium. It is of special interest to note that the winter of 1976-77 was one of the coldest on record in the area over the past 100 years. Nevertheless, the number of failures that occurred during this period of time was reduced from that of the previous winter which was less severe.

Results of Failure Surveys

Solely on the basis of the occurrence of additional failures after construction of the test sections, the data indicate that the overlay sections have performed better than any of the other test methods. A summary of failures that have occurred since construction of the test sections is listed in Table 4. In this Table the data are arranged in descending order relative to number of failures per 100 ft. (Also see Figures B6 to B15 in Appendix B).

It is apparent when looking at these data that the concrete shoulders were not effective in this particular experiment nor were the subdrains. As mentioned previously, a large portion of the concrete shoulder sections were concentrated at the southern end of the south bound lanes where poor performance had been demonstrated prior to the experiment and hence the data may be influenced by factors other than the use of shoulders themselves.

Likewise, the subdrains that were installed in this particular test project were relatively deep and are no doubt draining the subgrade as well as the subbase. Nevertheless,

MAINTENANCE METHODS	TOTAL LENGTH OF METHOD	1976 FAILURES	1977 FAILURES	TOTAL FAILURES	FAILURES PER 100'
Underseal and Overlay	6800	0	0	0	0.0
Overlay	6405	0	0	0	0.0
Overlay and Subdrains	495	0	0	0	0.0
Underseal	3600	1	2	3	0.08
Bituminous Patching	800	1	0	1	0.13
No Maintenance	3300	4	1	5	0.16
Concrete Patching	17190	27	17	44	0.26
Subdrains	5500	15	15	30	0.55
Concrete Shoulders	2855	9	7	16	0.56
Subdrains and Concrete Shoulders	1455	6	7	13	0.84
TOTALS	48400	63	49	112	0.23

TABLE 4. FAILURES PER MAINTENANCE METHOD

the back filling operation adjacent to the pavement edge was always carried up to the middepth of the concrete pavement and, therefore, any water that lays on the subbase should drain through the drains. It is known that the drains are not functioning and taking water from the pavement structure. The subbase under the pavement is impervious and contains a high percentage of fines. Therefore, percolation of the water through the subbase itself is probably not taking place and any water that is drained from the subbase is that which lies at the pavement-subbase interface. For this test section, this type of subdrain has not functioned.

Deflection Measurements

Deflection measurements taken in this study, were measured by the Dynaflect operated by the ISHC Research and Training Center. The Dynaflect, applies a repetitive rate of 8 cycles/second to the pavement, through two wheels (7). This frequency was chosen to retain comparability with static deflections, while maximizing speed and convenience of the measurements. A sensor (geophone), placed between the wheels, measures the deflection of the pavement in mils.

From Faiz's study (4), measurements taken 6 feet from the pavement edge showed that for 9 inch CRCP, deflections less than 0.5 mils are indicators of good pavement condition. Deflections in the range of 0.6-0.9 mils indicate a potential distress condition, while values above 1.0 mils are indicators of severe distress with a high probability of pavement breakups.

Deflection measurements were taken in this study for four uses. The first was to compare the deflections from Spring 1976 to Fall 1977 across each section. The second was to permit a statistical analysis of maintenance methods from Fall 1974 to Fall 1976. The third purpose was to compare the differences in deflection over two time periods, for 10 test patches. The plots of the 10 patches are shown in Figures E1 to E10 in Appendix E. The last reason was to determine the significance of keyed versus non-keyed concrete shoulder sections and the significance of the deflection associated with the joint of the shoulder versus the deflection between the joints.

Deflection as a Function of Season of Year

The results of the change in deflection from Spring 1976 to Fall 1977, are found in Table C1 to C2 in Appendix C. The data indicate higher deflection in the spring than in the fall. This is not true in every section, but it is definitely a general trend. High spring readings are influenced largely by subgrade weakening during the frost-melt period.

Comparison of Deflections of Various Maintenance Sections

The purpose of the statistical analysis presented below is to determine 1) the way the deflection measurements varied throughout time, and 2) if there is any significant difference between any of the maintenance methods. A second analysis, which will be discussed later, involves the interaction of time with different overlay thicknesses. A third analysis

involves the significance of keyways, tie-bar spacing, and joint deflections within the concrete shoulder sections.

Procedure. Deflection measurements were taken at six different time periods and were taken every 25 feet on the outer wheel path. The lengths of each section were unequal, due to criteria set up before construction. The number of deflections measurements within a section varied from 4 to 204.

Method and Layout. The entire experimental procedure was repeated six times from fall 1974 to fall 1976; this blocking over time is represented by T. The experiment divided the road in many sections (from 1 to 9) for each maintenance method. The sections are denoted by S. Therefore, the sections are nested with the maintenance method (denoted by M). An observation was taken every 25 feet within each section, and one deflection measurement (denoted by Y) was taken for each observation. Therefore, the observations (denoted by O) are nested with sections. The model of this experiment is:

$$Y_{ijkl} = (u + M_i + S_{(i)j} + O_{(ij)k} + S_{(ijk)} + T_l + MT_{il} + ST_{(i)jl} + OT_{(ij)kl} + E_{(ijkl)})$$

where: $i = 1....10$

$j = 1....J$ J varies from 1 to 9

$k = 1....K$ K varies from 4 to 204

$l = 1....6$

and: Y_{ijkl} = deflection measurements

u = overall means

M_i = effect due to the ith maintenance method

$S_{(i)j}$ = effect due to jth section applied to the ith maintenance method

$O_{(ij)k}$ = effect due to kth observation in the jth section which is applied to the ith maintenance method

$S_{(ijk)}$ = restriction error

T_l = effect due to the lth time period taking the measurement

MT_{il} = Effect due to the interaction between ith maintenance method and time period

$ST_{(i)jl}$ = effect due to the interaction of the jth section which applied ith maintenance method under lth time period

$OT_{(ij)kl}$ = effect due to the interaction of the kth observation in the jth section which applied ith maintenance method under lth time period

$E_{(ijkl)}$ = within error, since there is only one observation per call, there are 0 degrees of freedom

Analysis. In performing the statistical analysis, the goal was to use all the data from each time period, but in this case both the sections and maintenance methods were unbalanced. The problem was therefore handled using the following criteria.

1) Make every level balanced by random sampling, using means for cells which had too few data observations within S.

   a) Sections (varies from 1 to 9): Take 3 sections. For sections greater than 3: Sample at random

For sections less than 3: Repeat sections by means

b) Observations (varies from 4 to 204): Take 10 observations per section.

For observations greater than 10: Sample at random

For observations less than 10: Repeat observations by means.

2) Keep original M, S, T, but sample the observations to make O balance. Therefore, take 10 observations per section.

3) Do everything (using all available data).

In doing analysis (1), S and O were selected by random sampling which made the original experimental model become:

$$\overset{1800}{Y_{ijkl}} = (u + \overset{9}{M_i} + \overset{20}{S_{(i)j}} + S_{(ij)} + \overset{5}{T_l} + \overset{45}{MT_{il}} + \overset{100}{ST_{(i)jl}} + \overset{1620}{E_{(ijl)k}})$$

where $i = 1....10$

$j = 1....3$

$k = 1....10$

$l = 1....6$

The 1800 pieces of data were analyzed by the BMD8V Statistical program. The ANOVA Table from our design is found in Table 5. From the ANOVA Table it is noticed than both M_i and T_l (which are of interest) are significant at the $Q = 0.05$ level, and the MT_{il} is also significant at $Q = 0.05$ level. Since the interaction term MT_{il} is significant, any further analysis of the results is to plot the cell means over time for all 10 maintenance methods (See Figure 5 for

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F TEST	F CRIT. .05
M_i	9	4.09	.45	3.75*	2.39
$S_{(i)j}$	20	2.42	.12		
$S_{(ij)}$	0	None			
T_ℓ	5	11.18	2.24	41.2*	2.33
$MT_{i\ell}$	45	9.93	.22	4.1*	2
$ST_{(i)j\ell}$	100	5.42	.054	1.9*	1.25
$E_{(ij\ell)k}$	1620	45.5	.028		

*Denotes F Test is Significant at 0.05 Level

TABLE 5. ANOVA, DEFLECTION OF MAINTENANCE SECTIONS WITH TIME

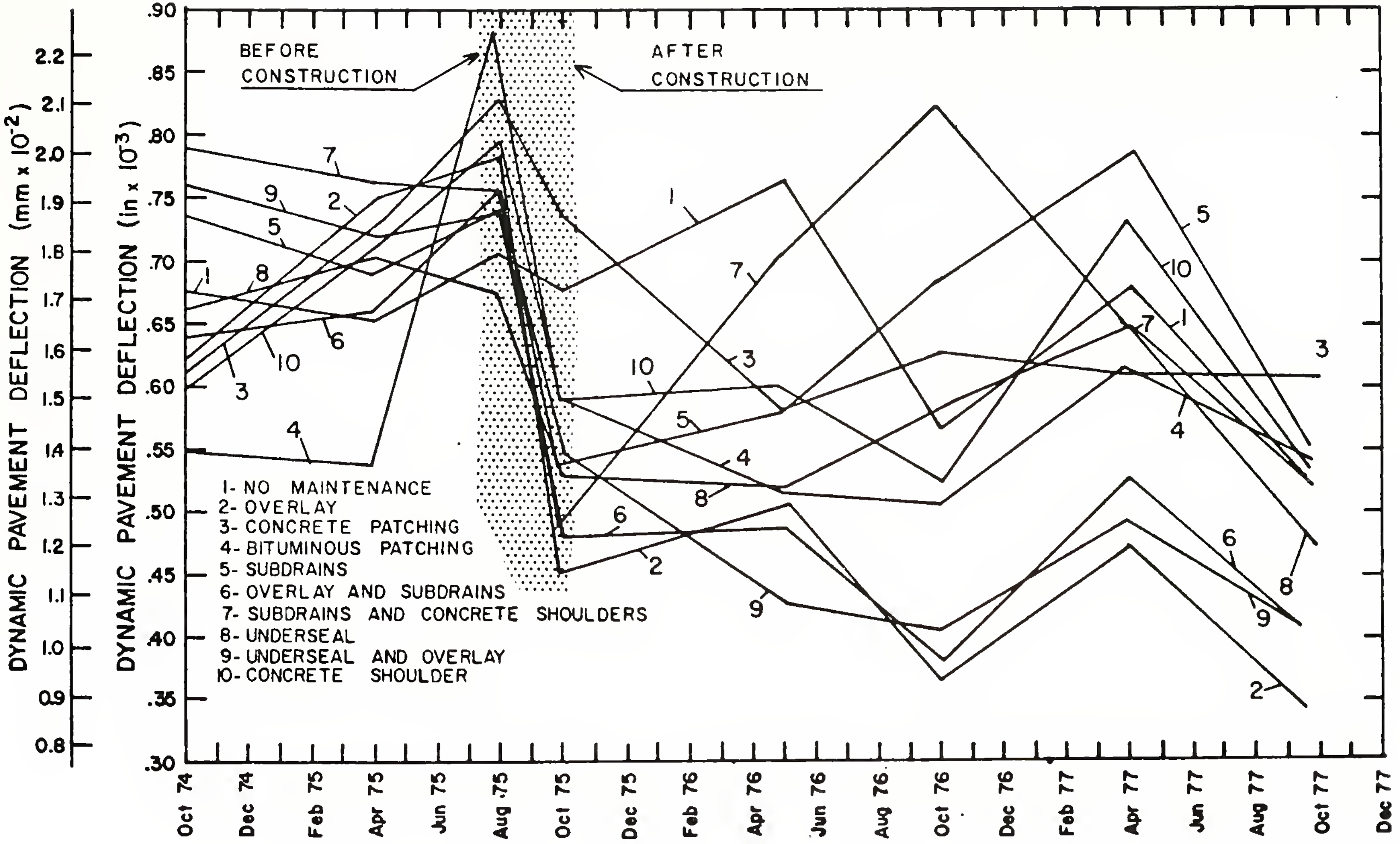


FIGURE 5. MEAN DEFLECTION vs. TIME

the combination plot of all 10 maintenance methods and Table 6 for the cell means data).

It is seen that the interactions are significant, due to the fact that many of the different maintenance method lines (See Figure 5) cross each other. For this reason, the main effects are of interest since they are statistically significant.

Normally, a Newman-Keuls test would be used to rank the cell means, but there is too much crossing over of the cell means to show any sort of trend. In order to explain what is actually happening, it becomes necessary to plot the cell means of each maintenance method vs. time, individually (See Figure C3 to C12 in Appendix C).

Deflection For the Various Maintenance Methods. By the analysis of variance, the tests of the main effects (maintenance methods and time) are significant at Q =0.05 confidence level, and the interaction term is also significant. Therefore, it is concluded that there is a significant difference between each maintenance method over time, and it becomes necessary to look at the plots (See Figures C3 to C12 in Appendix C) to see how each maintenance method interacted with time.

To evaluate the influence of the maintenance methods on deflection over a period of time, and conversely to be able to use deflection measurements to estimate the probable future behavior of the maintenance sections, it is necessary to look at the shapes of the curves which show deflection over a

MAINTENANCE METHODS	TIME					
	1	2	3	4	5	6
1	.60	.71	.80	.59	.60	.52
2	.61	.72	.83	.74	.58	.63
3	.62	.75	.78	.45	.51	.37
4	.68	.65	.71	.68	.76	.57
5	.55	.54	.89	.59	.52	.51
6	.76	.72	.74	.55	.43	.41
7	.66	.70	.67	.53	.52	.59
8	.74	.69	.74	.54	.58	.69
9	.79	.76	.76	.49	.71	.83
10	.64	.66	.76	.49	.49	.39

MAINTENANCE METHODS	
1	CONCRETE SHOULDER
2	CONCRETE PATCHING
3	OVERLAY
4	NO MAINTENANCE
5	BITUMENOUS PATCHING
6	UNDERSEAL AND OVERLAY
7	UNDERSEAL
8	SUBDRAINS
9	SUBDRAINS AND OVERLAY
10	OVERLAY AND SUBDRAINS

TIME	
1	OCTOBER 1974
2	APRIL 1975
3	AUGUST 1975
4	OCTOBER 1975
5	MAY 1976
6	OCTOBER 1976

TABLE 6. CELL MEANS OF DEFLECTION FOR MAINTENANCE METHODS OVER TIME

period of time as in Figures C3 to C12 in Appendix C. A cursory review of these curves shows that those sections showing the best performance have a general trend of decreased deflection with time. On the other hand, those sections that have shown poor performance have increased deflections over those shown immediately after construction. Therefore, the data suggest that the poorer performing sections are becoming further weakened with heavy traffic over time, whereas those sections showing good performance appear to be more stable (as reflected by the deflection measurements) as time progresses.

This is further illustrated in the data shown in Table 7. In this Table the average deflection of the various test sections immediately before construction and after construction are listed in the first two columns. At first glance, each of the maintenance methods reduced the deflections significantly (with the exception of the control sections). This is reflected in the third column which shows the percent change of deflection from the before to after condition. With the exception of the control sections the percent change in deflection from the before to the after condition averaged about 31 percent as compared to an average of 9 percent for the control sections. The maximum change in deflection for the test pavements was 41 percent whereas the minimum was 26 percent.

The data in Table 7 are arranged in the same order as the data relating to failures. Those sections at the top

Maintenance Method	Average Deflection Prior to Constr.	Average Defl. after Constr.	% change before to after	Maximum Deflec.	% change before to maximum	Average Deflec. Fall 1977	% change after to Fall 77
Underseal and Overlay	0.73	0.54	-28	0.54	0	0.40	-26
Overlay	0.77	0.45	-41	0.51	13	0.32	-28
Overlay and Subdrains	0.75	0.46	-39	0.58	26	0.34	-26
Underseal	0.66	0.52	-21	0.63	21	0.45	-16
Bituminous Patching	0.89	0.58	-35	0.60	3	0.52	-10
*No Maintenance	0.70	0.65	-7	0.75	15	0.52	-20
*Concrete Patching	0.82	0.73	-11	0.67	-8	0.60	-18
Subdrains	0.74	0.53	-28	0.77	31	0.52	-1
Concrete Shoulder	0.78	0.57	-26	0.73	28	0.54	-5
Subdrains and Concrete Shoulders	0.75	0.48	-36	0.82	70	0.50	4

*Section that originally had no failures and should be considered to be a control section.

**Control sections which were patched only.

TABLE 7. PERCENT CHANGE IN DEFLECTION OVER TIME

of the Table have shown the best performance, while those at the bottom of the Table have shown the poorest performance.

Another indicator of the performance can be seen in the 7th column from the left where the percent change in deflection from the after condition to fall of 1977 condition is shown. These, it is to be recalled, are both fall readings; the first being that immediately after construction and the latter the latest data that have been obtained. It is to be seen that those sections showing good performance are showing negative percent changes in deflection of a fairly high magnitude whereas those with poor performance the reverse is true.

Solely on a qualitative basis the data suggest that the overlay sections are functioning well and every indication is that their performance will continue to be good over a period of time. On the other hand, some reflection cracking has been noted on the feather sections.

Statistical Analysis of Overlay Thickness

In this analysis, the object was to determine the significance, if any, of the depth of overlay. As was discussed earlier, the three depths of overlay sections were 2", 3" and 5", which were distributed between 1082+00 and 1152+00 in the northbound lane. A second objective within this analysis, was to determine if there is any difference in deflection measurements with respect to time, within each type of the three overlay thicknesses.

Procedure. Although the test section for variable thickness overlays was from 1082+00-1152+00 in the northbound lane, just the distance from 1101+00-1138+00 was considered in the analysis. This was due to the fact that the northbound section 1082+00-1101+00 was undersealed in addition to having an overlay, and the section from stations 1138+00-1148+00 had subdrains and underseal at various locations in addition to the overlay (See Figure 1).

Deflection measurements were taken every 25 feet along the sections, at six different time periods from Fall 1974 to Fall 1976. Those measurements that were within 100 feet either side of the point where the overlay changed thickness, were dropped from the analysis because they were in transition zones and, therefore, could be associated with either of the two thicknesses. Each point where a deflection measurement was included in the analysis, was termed as a "section" (denoted by S). There were 36 sections associated with the 2" overlay, 72 sections associated with the 3" overlay, and 40 sections associated with the 5" overlay. Each deflection measurement was designated by Y, each overlay thickness was designated by 0, and each time period was designated by T.

Model. The model of the overlay analysis is as follows:

$$Y_{ijk}=(u + 0_i + S_{(i)j} + S_{(ij)} + T_k + 0T_{ik} + ST_{(i)jk} + E_{(ijk)})$$

where: $i = 1....3$

$j = 1....J$ J varies according to each type of overlay

$k = 1....6$

and: Y_{ijk} = deflection measurements

u = overall mean

O_i = effect due to the ith overlay type

$S_{(i)j}$ = effect due to the jth section applied to the ith overlay type

$S_{(ij)}$ = restriction error

T_k = effect due to the kth time period

OT_{ik} = effect due to the interaction of the ith overlay during kth time period

$ST_{(i)jk}$ = effect due to the interaction of the jth section of the ith overlay during the kth period of time

$E_{(ijk)}$ = within error, with 0 degrees of freedom, because there is only one observation within the jth section

Analysis. The S terms are unbalanced, so therefore it is difficult to run the data using BMD8V or SPSS ANOVA due to the large number of data points. Therefore, it was decided to balance the S terms into groups of 36 by making 2 groups of 3" overlay and by deducting 4 data points from the 5" group. The new model is as follows:

$$Y_{ijk} = (u + O_i + S_{(i)j} + S_{(ij)} + T_k + OT_{ik} + ST_{(i)jk} + E_{(ijk)})$$

where: $i = 1 \ldots 3$

$j = 1 \ldots 36$

$k = 1 \ldots 6$

The BMD8V program was used to evaluate the model, and the results are found in Table 8. From the ANOVA in Table 8, it is found that both the main effect of time and the interaction term of overlay and time are significant at $Q = 0.05$ level. Since the F test for OT_{ik} is significant, the cell means of each overlay thickness (3" overlay will have two plots because the 72 measurements were divided into 2 sets of 36 measurements) were plotted against time (See Figure 6). Each overlay thickness was plotted individually against time to observe how each overlay thickness varied with time (See Figures C13 to C16 in Appendix C). From Figure 6 it is observed that the deflection means cross throughout time, hence there is no interest in the main effects although they are significant.

Conclusion, Deflection and Overlay Thickness. It is found from Figure 6 that none of the overlay thicknesses can be predicted to have lower deflection measurements than the other 2 overlay thicknesses. It should be recalled that this analysis is only over two years, and hence, there is some question whether these results would be different if the analysis was performed over a longer time period.

Effect of Concrete Shoulder on Deflection

The concrete shoulder sections contain many variables within each section. The main variable is whether the concrete shoulder contains a keyway. The only concrete shoulder section containing a keyway is on the southbound lane between sections 1224+00-1212+00 (See Figure 2).

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F TEST	F CRIT. .05
O_i	3	.51	.17	1.01	2.60
$S_{i(j)}$	140	23.4	.17		
$S_{(ij)}$	0	None			
T_k	5	.14	.03	3.16*	2.90
OT_{ik}	15	.46	.03	3.41*	1.67
$ST_{(i)jk}$	700	6.24	.01		
$E_{(ijk)}$	0	None			

* DENOTES F TEST IS SIGNIFICANT AT Q=0.5 LEVEL

TABLE 8. ANOVA, EFFECT OF OVERLAY THICKNESS

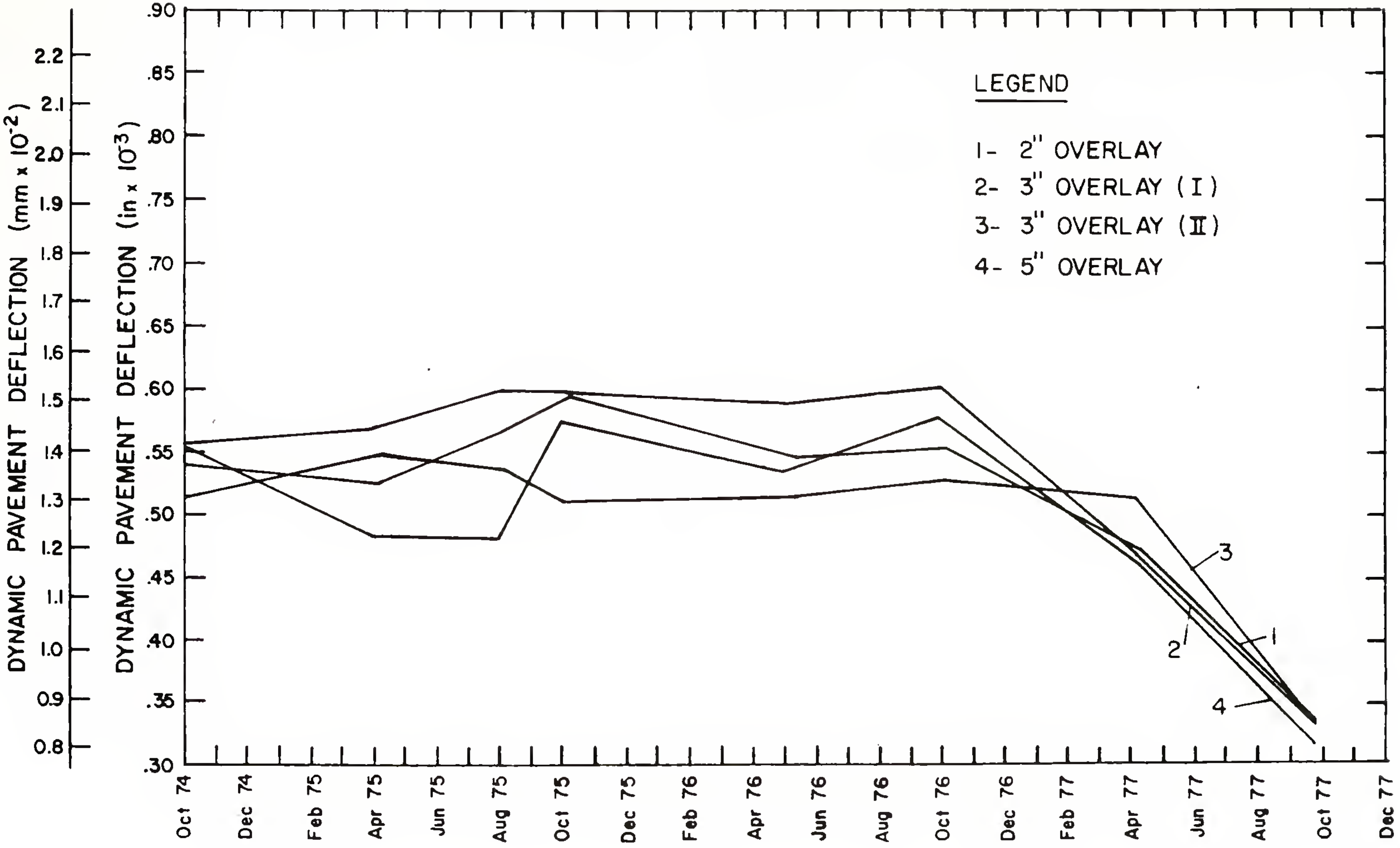


FIGURE 6. MEAN DEFLECTION vs. TIME - COMBINATION OF OVERLAY SECTIONS

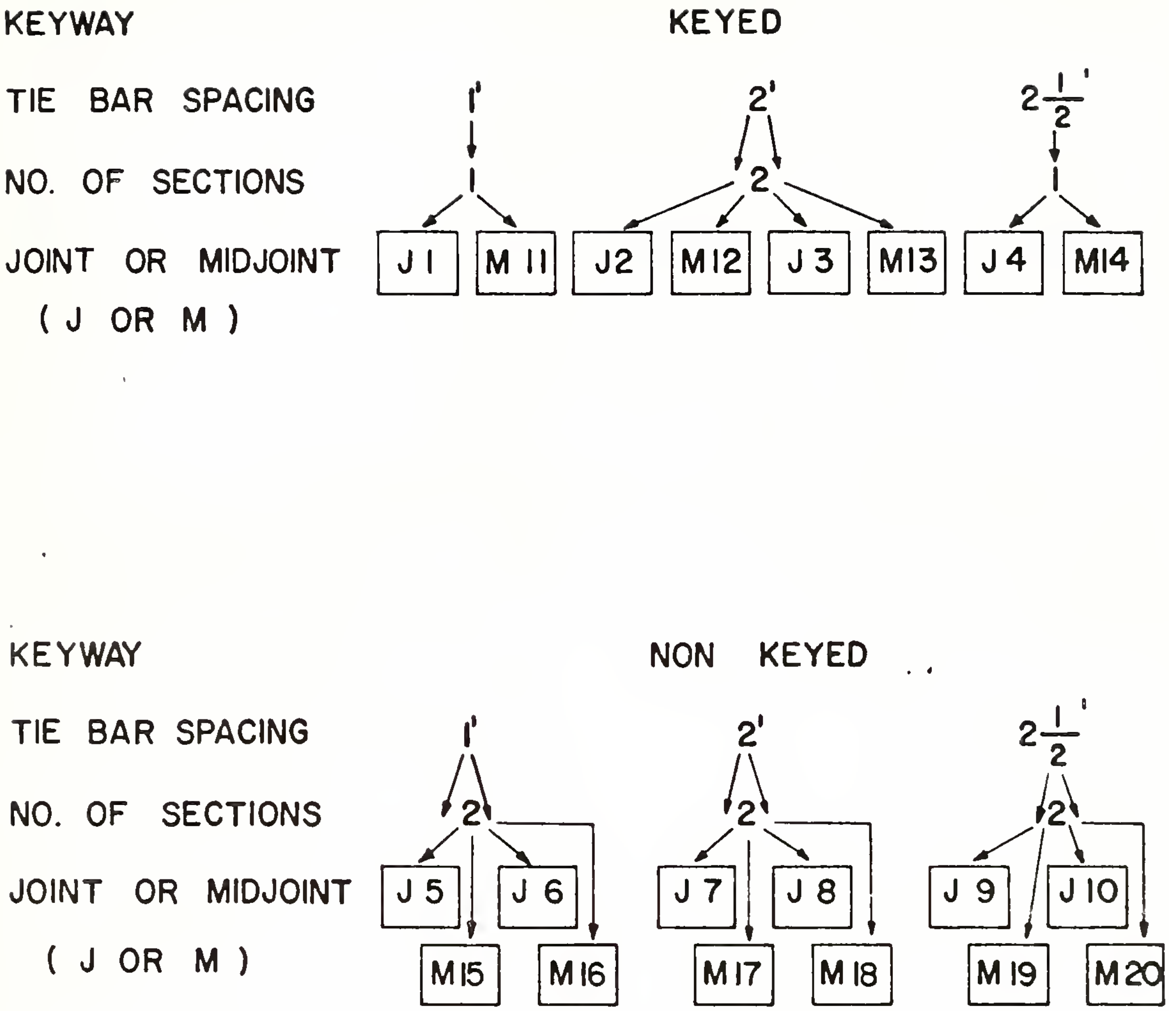
Another variable involves the spacing of tie bars (which holds the shoulder to the existing pavement). Every concrete shoulder section contained tie bars, and the spacings are shown in Figure 3. Deflection measurements were taken at the joint and midjoint of each concrete shoulder slab, and each measurement was classified as to whether it was within the 12-inch, 24-inch or 30-inch tie bar spacing section.

The last variable involved the separation of the joint measurements from the midjoint measurements. Earlier in the research, it was hypothesized that the joint measurements would be higher than the midjoint measurements, owing to the fact that there is no tie bar at the joint (See Figure 3).

Since there was an excess of data, it was decided that certain sections would be divided into 2 equal sections. The layout had 20 sections and is seen in Figure 7.

The first test to perform was the Bartlett Box Test, which shows whether the data is homogenous or not. If the data is non-homogenous it is impossible to determine whether the data is significant. The Bartlett Box Test was performed on the Spring 1976 and Fall 1976 data, and also a combination of the two time periods.

Each of the three cases proved that the data was non-homogenous, by the randomness of the data, and consequently it would be useless to continue further. A statistical program, SPSS ONEWAY, was used for the Bartlett Box Test, and a resulting F test probability of 0.0 also supported the conclusion that the data was non-homogenous.



Note: See Figures 2 and 3 for Joint Layout

FIGURE 7. LAYOUT OF STATISTCAL MODEL FOR CONCRETE SHOULDERS

There appeared to be some difference between deflections in the keyed and non-keyed joints in the 1976 survey but these differences disappeared in the 1977 surveys. The data on the whole as stated above show no significant differences when considering keys, bar spacing or deflections at joints as compared to mid-span (Tables D1 to D4 in Appendix D).

Deflection Measurements at Failures and Patches

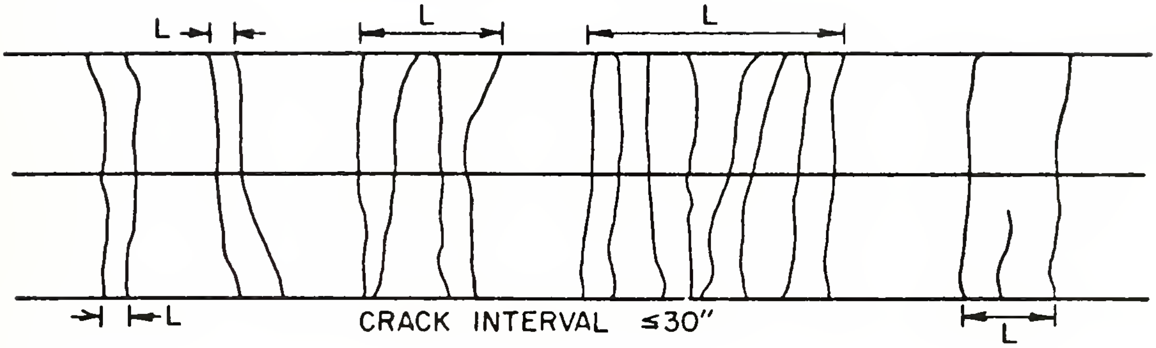
Of the 27 patches that were tested (see previous section of this report titled "Special Deflection Measurements"), four had failures associated with the patch. Reasons for patch failures were not determined in the test.

It should be noted that 4 out of 27 failures are much less than the 1976 and 1977 totals of 44 out of 112 failures. The testing method seems to be effective, and it is a recommended procedure to continue, although some modification of the criteria may be necessary.

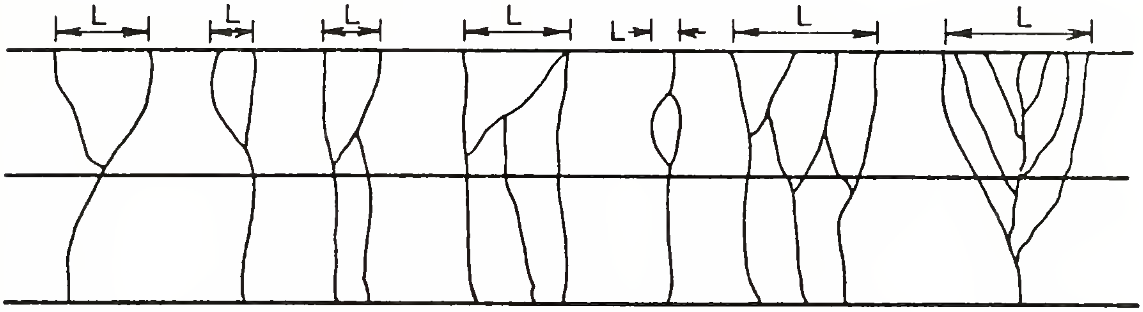
Crack Analysis

Crack spacing is another way in which performance over time can be measured. For this study only those cracks that were less than 30 inches apart were considered. Figure 8

PARALLEL CRACKS



INTERSECTING CRACKS



COMBINED PARALLEL AND INTERSECTING CRACKS

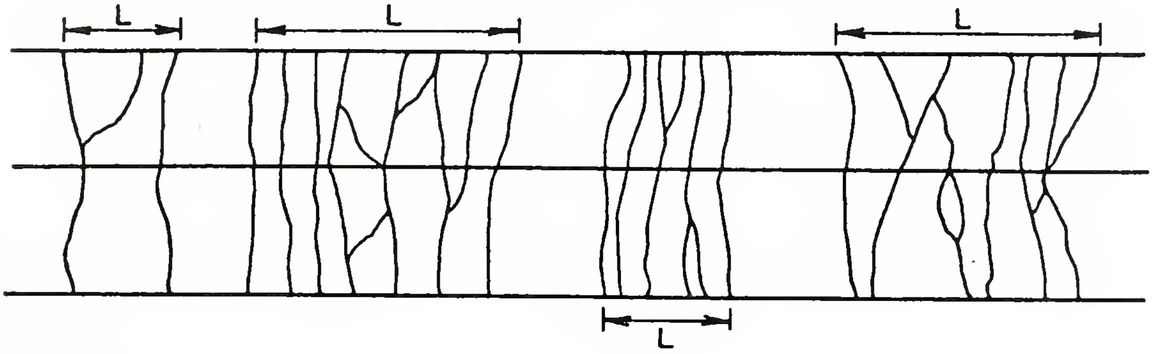


FIGURE 8. TYPICAL CRACK PATTERNS

displays the three typical crack configurations found. The distance L in every case is the lineal feet of pavement with cracks spaced less than 30 inches. Length of cracked joints were estimated by sight, and therefore is subjected to some operator error.

The lineal feet of cracking of each section were totaled, and then divided by number of stations in each section. These computed values are found in Tables 9 to 10 for each of the four time periods.

Results

Cracking did not increase appreciably during the experiment, although the Spring 1976 crack lengths were slightly larger in most cases. The data were constant throughout time, and the only cause for fluctuations in data, is the estimation procedures.

STATION NUMBER	SPRING '76	FALL '76	SPR. '77	FALL '77
990 - 995 SBL	12.6	9.6	8.4	10.4
995 - 996 SBL	3.0	3.0	3.0	3.0
996 - 1001 SBL	8.0	7.2	8.2	7.0
1001 - 1008 SBL	10.1	5.9	6.0	6.4
1008 - 1018+50 SBL	13.9	9.0	8.4	9.3
1018+50 - 1033 SBL	10.8	9.2	12.0	11.9
1033 - 1036 SBL	6.7	2.3	3.0	5.3
1036 - 1050 SBL	Overlay	Overlay	Overlay	Overlay
1050 - 1059 SBL	5.7	3.6	5.2	5.6
1059 - 1090 SBL	7.3	6.6	6.2	6.1
1090 - 1141 SBL	9.9	7.6	7.0	7.1
1141 - 1171 SBL	Overlay	Overlay	Overlay	Overlay
1171 - 1196 SBL	16.5	10.7	12.4	13.6
1196 - 1204 SBL	15.7	10.1	7.8	11.3
1204 - 1209 SBL	34.2	23.0	15.8	24.2
1212 - 1224 SBL	25.0	17.3	14.6	21.6
1224 - 1235 SBL	30.1	19.2	18.3	21.2

Note: Cracking is in Lineal Feet per 100 Lineal Feet of Pavement.

TABLE 9. LINEAL FEET OF CLOSELY SPACED CRACKS PER 100 FEET

STATION NUMBER	SPRING '76	FALL '76	SPR. '77	FALL '77
990 - 994 NBL	15.0	15.5	13.5	17.0
994 - 1025 NBL	9.9	9.0	6.6	10.2
1025 - 1065 NBL	10.5	10.5	8.0	11.1
1065 - 1066 NBL	46.0	44.0	52.0	32.0
1066 - 1072 NBL	18.0	16.2	17.2	17.5
1072 - 1082 NBL	11.0	9.6	9.1	8.8
1082 - 1101 NBL	Overlay	Overlay	Overlay	Overlay
1101 - 1138 NBL	Overlay	Overlay	Overlay	Overlay
1138 - 1143 NBL	Overlay	Overlay	Overlay	Overlay
1143 - 1148 NBL	Overlay	Overlay	Overlay	Overlay
1148 - 1152 NBL	Overlay	Overlay	Overlay	Overlay
1152 - 1161 NBL	8.3	5.6	5.9	7.4
1161 - 1167 NBL	26.0	12.8	18.0	19.0
1167 - 1172 NBL	31.6	28.4	27.4	29.0
1172 - 1176 NBL	36.7	37.0	36.0	34.5
1176 - 1209 NBL	18.0	16.8	16.0	16.3
1212 - 1235 NBL	Overlay	Overlay	Overlay	Overlay

NOTE: CRACK LINEAL FEET IS MEASURED IN FEET

TABLE 10. LINEAL FEET OF CLOSELY SPACED CRACKS PER 100 FEET

COST ANALYSIS

The cost analysis achieved on this project consisted of a cost evaluation which indicates the cost effectiveness of the various methods. Due to the small time period in which data has been collected (two years), it is not possible to predict the number of patches in each section that might occur later, although failure progression is slowing down. Accordingly, the cost data for the past two years has been collected and tabulated in Appendix F. Owing to the fact that there was no patching performed in 1977, as was expected, and there was little routine maintenance done, these data have been eliminated from the analysis.

All costs for original construction were obtained from original contract records at the ISHC office in Indianapolis. The 1976 patching costs were also obtained from contract records. Routine maintenance costs associated with failures were derived from ISHC maintenance records for interstate highways in the Amity Sub-District. This routine maintenance cost was obtained by multiplying the per mile cost by approximately 20 lane miles, and then dividing by the number of patches. The routine maintenance cost used in the analysis was $23.50 per patch. Primary costs were the major maintenance costs of concrete patching.

Conclusion

There were four sections which had no maintenance costs. These were Sections C, O, R and FF. Section U was removed from the analysis, because it was a small section, and the two bridge sections were also excluded from the analysis.

The total cost for each section of the individual maintenance methods, were summed together. The results are given in Table 11, which shows total cost, feet of each maintenance method, and cost/100'.

Solely on the basis of cost the two methods that showed high values were concrete shoulder and subdrain plus concrete shoulder methods. They both exceeded $3,000/100' although both methods were not long in length. The other three that were over the average of $1,235/100' are overlay and subdrains at $2,157/100', overlay at $1,874/100' and the underseal and overlay at $1,511/100'. Bituminous patching had a cost of $1,152/100', but this is not an accurate reflection of its true cost, due to its short section length. Subdrains had a cost of $1,008/100' while concrete patching alone (control sections), with a very long section length, had a cost of $838/100'.

The estimated cost of 1977 failures that were not patched, was added to the cost of the two previous years for each maintenance method, and placed in Table 11. The estimated cost to patch a failure and perform routine maintenance was $2055/100'.

Maintenance Method	Total Length (feet)	Total Cost through 1976	Total Cost through 1976 ($ per 100')	Failures		Total*** Est. Cost through 77 ($ /100')
				Number	No./100'	
Underseal and Overlay	6800	105,485	1,511	0	0.0	1,511
2" Underseal and Overlay	2800	22,922	817	0	0.0	817
3" Underseal and Overlay	4000	82,563	2,064	0	0.0	2,064
Overlay	6405	119,974	1,873	0	0.0	1,873
2" Overlay	900	11,933	1,326	0	0.0	1,326
3" Overlay	4505	87,926	1,952	0	0.0	1,952
5" Overlay	1000	20,115	2,011	0	0.0	2,011
Overlay and Subdrains	495	10,784	2,179	0	0.0	2,179
Underseal	3600	11,197	311	3	0.08	425
Bituminous Patching	800	9,218	1,152	1	0.13	1,152
*No Maintenance	3200	5,301	165	5	0.16	230
**Concrete Patching	17190	142,301	838	44	0.26	1,036
Subdrains	5500	55,445	1,008	30	0.55	1,569
Concrete Shoulders	2855	85,792	3,010	16	0.56	3,509
Subdrains and Concrete Shoulders	1455	51,084	3,511	13	0.84	4,500
TOTALS	48300	596,581	1,235	112	0.23	1,444

Note: All costs include cost of initial maintenance construction plus maintenance costs through 1976 and 1977.

*Section that originally had no failures and should be considered a control section.

**Control sections which were patched only.

***Includes estimated cost if 1977 failures had been patched.

TABLE II. TOTAL COST BREAKDOWN

EVALUATION OF MAINTENANCE METHODS

The purpose of this study has been to evaluate each of the maintenance methods with respect to performance and cost. It is possible to eliminate a portion of the maintenance methods due to poor performance and high cost. Several of these methods performed badly under the present construction as will be discussed in later paragraphs.

Underseal and Overlay

Underseal and overlay sections have performed very well, although it is not known what the contribution of the underseal is opposed to the overlay. For this reason, the underseal and overlay sections should be observed in the future.

The underseal and overlay sections have maintained very low deflections compared to relatively high deflections before construction. This phenomenon is probably due primarily to the overlay which seems to reduce deflections. There have been no failures observed within the underseal and overlay method of 6,800 feet.

The cost for the underseal and overlay sections is $105,485 or $1,511 per 100 feet. This cost is again fairly high.

Asphalt Overlay

The asphalt overlay sections have performed very well over the period of two years they have been in service.

Various thicknesses have been examined to determine if performance is affected by the difference in overlay thicknesses. The overlay thicknesses examined, (2", 3", and 5") behaved differently within the group, but one thickness could not be predicted to experience lower deflections than another.

Low deflection measurements have been experienced in the overlay sections since construction was performed in 1975. The overlay sections have averaged the lowest deflections of any of the maintenance sections.

The overlay sections have not experienced failures since their construction. The overlay sections total 6,405 feet. The overlay sections are obviously delaying additional distress of the CRC pavement. Nevertheless, it is advisable to observe the overlay sections in future years. Reflective cracking is observed in the very thin overlay sections (i. e. feather ramps), which indicates potential distress in the overlay.

The overlay sections have a cost of $1,873. per 100 feet. This cost is high compared to the other methods, which may limit its use, but on the other hand has been the most effective method used.

Overlay and Subdrains

The test section for overlay and subdrains is only 495 feet which is too short to obtain accurate conclusions. This section should be observed in the future to determine performance of the overlay section.

Deflections have been low since construction in the summer of 1975. Low deflections were no doubt due to the overlay which may distort the actual deflections.

There were no failures within the overlay and subdrain section, also due to the overlay itself. Overlay and subdrain sections have performed well, but at this time, the other two overlay methods have performed as well at a lower cost.

The overlay and subdrain method cost $10,784 or $2,179 per 100 feet.

Undersealing

The underseal method performed well under each analysis, and should be considered as a viable method.

Underseal sections experienced low to moderate deflections, shown in Figure 5. This is surprising, due to the fact that undersealing was only performed in underseal sections where deflection was greater than 0.9 mils. From Figure 5, underseal seemed to lower deflections from near an average of near 0.7 mils to near 0.5 mils.

Undersealing was only done where the deflection was greater than 0.9 mils. The underseal method has had failures where the deflection was less than 0.9 mils, but has experienced no failures where the pavement was actually undersealed. A potential failure in the southbound lane at station 1074+50 was undersealed and is still performing well after two years.

This indicates that good performance was instilled wherever underseal was actually used.

The method adopted in this study of selecting the areas needing undersealing (deflections greater than 0.9 mils) no doubt needs revision. It would perhaps be best to underseal a pavement as a routine matter prior to application of an overlay, if there is any reason to believe that a potential void exists under the pavement.

Undersealing should be considered as a viable maintenance method due to it's good performance and cost effectiveness. It should be noted, though, that there is danger in undersealing a pavement where there are no voids between the subbase and the pavement.

Bituminous Patches

Bituminous patches in this experiment have behaved very well, although only 5 have been constructed and only two of the five are within the bituminous patching section. Due to the small number of patches and short test section, the results must be modified accordingly.

The 5 bituminous patches have performed well with no failures associated with the patches. The large bituminous patch itself at station No. 1200+50SBL has shown no distress or failures.

The only bituminous patching section, has experienced moderate and stable deflections, except in the fall of 1975. The deflections should not fluctuate, because the maintenance

method is not relieving stresses within the total length of the section.

The total cost for the bituminous patching section is $9,218 or $1,152 per 100 feet. This cost does not include the cost of the three bituminous patches outside of the section. This cost is slightly higher than concrete patching sections, although the performance is much better.

The performance of the bituminous patches has been somewhat surprising in that it is generally considered necessary to maintain continuity of the reinforcing steel through the use of concrete patches. It is perhaps too early to predict the potential outcome of this type of maintenance but it bears further observation. It would be wise to study other bituminous patches on other roads for a comparison.

Concrete Patching Only (Control Sections)

Every maintenance section was repaired with concrete patches prior to application of any other maintenance method. Hence, the "concrete patching only" sections were used as a control for the other test sections.

The concrete patch control sections experienced 27 failures in 1976 and 17 failures in 1977 over a length of 17,190 feet. The number of failures per 100 feet for the control sections was slightly more than the average.

These control sections experienced relatively high deflections that have not fluctuated greatly over time, although very high deflections were experienced in the fall

of 1975. Reasons why deflections in these sections have not fluctuated since applying the patch, include the principle that patching essentially restores the pavement to its original condition and does nothing to improve it.

The total cost for the concrete patching sections was $142,301 or $838 per 100 feet.

In sections where concrete patches alone were used, many of these patches experienced failures adjacent to them. There are perhaps several reasons for this including poor compaction of the subbase under the steel after it is placed, and potential breaks caused between the saw cuts due to impact of the machine breaking up the concrete of the patch.

Subdrains

The subdrains did not perform as well as was expected, considering the fact that water beneath the pavement was a major problem. The subdrains did not improve performance of the pavement because something obviously did not effectively remove the water between the pavement and the subbase.

The number of failures within the subdrain sections totaled 30 in 5,500 feet with 15 failures in 1976 and 15 in 1977 (Table 4). There were far more failures than expected within the subdrain sections indicating poor performance.

The subdrain sections experienced higher than normal deflections, although the deflections were moderate in the winter of 1975-1976 (from Figure 5). Again, these deflection

measurements are indicative of poor performance and distress within the pavement.

The total cost for the subdrains amounted to $55,445 or $1,008 per 100 feet. This figure is near the average of the 10 maintenance methods, and if the technique can be improved, it should be seriously considered.

Each of the subdrain outlets were observed in May of 1977. They were observed a few days after a heavy rain. Only 2 out of 14 subdrains seemed to be draining water, and both of these were only "tricklers".

It is believed that low permeability of the subbase is the major source of problems with the subdrains. The technique of draining existing pavements such as the one under study should be reviewed and changed if needed. In particular, the location and size of the pipe should be reviewed, and the outlet should permit easy removal of excess water.

Free water beneath the pavement is a major problem, and if a subdrain is developed that effectively removes water from the subbase, it would be a desirable maintenance method.

Concrete Shoulders

Concrete shoulders will be differentiated into two classes; keyway and non-keyway. The non-keyed shoulders have not performed well and have experienced far more failures than had been anticipated, shown in Table 1. On the contrary, the keyed shoulder section has performed very well

with one failure since construction. The deflection measurements have also been higher for the non-keyed sections than the keyed section.

There seems to be no significant difference between the number of failures associated with the different tie bar spacings.

The cost of concrete shoulders found in Table 11 totaled $85,792 which amounted to $3,010 per 100 feet. This cost does not differentiate between keyed or non-keyed sections, although the non-keyed sections are more expensive due to the greater number of failures. The cost of $3,010 per 100 feet is the second highest cost, next only to subdrains plus concrete shoulders.

Concrete shoulder sections were among those methods with higher deflections, shown in Figure 5. This figure is a composite of all concrete shoulder sections, and does not distinguish between keyed and non-keyed.

In summary, the results of this study suggest a non-keyed concrete shoulder should not be recommended as a maintenance method for a CRC pavement, due to the high number of failures, high deflection measurements, and expensive initial costs. If a keyway exists at the pavement edge this may be a viable method of maintenance.

Subdrain and Concrete Shoulders

The subdrain and concrete shoulder sections did not perform well, due to unkeyed concrete shoulders and poorly

constructed subdrains. Defelctions within the subdrain and concrete shoulder sections were erratically high. The deflections indicated poor performance with high distress in the pavement.

Subdrain and concrete shoulder sections encountered 6 failures in 1976 and 7 failures in 1977 over 1455 feet. This is much worse than the average of the maintenance methods, which again indicates very poor performance.

A cost of $51,084 or $3,511 per 100 feet for subdrains and concrete shoulders was the highest cost of any maintenance method.

SUMMARY AND RECOMMENDATIONS

Basically three major types of maintenance were investigated in the research project over and above the normal concrete patching which is done on a routine basis in the state. Various combinations of these maintenance techniques were used and variations of the methods were included in some cases. The basic methods included the following:

1. Overlay with asphalt concrete both with and without drainage and undersealing.
2. Installation of subdrains at the outside edge of the pavement.
3. Concrete shoulders.

It is pertinent to note first, that the test pavement was among the worst performing pavements in the state at the time the experiment was set up. As mentioned in the Introduction of this report, the test pavement included all of the factors known to be contributors to poor performance of continuously reinforced concrete pavements in Indiana. Because of the high incidence of failures in the test pavement prior to establishing the maintenance experiment, it can be argued that the results of the experiment itself have been influenced by the initial condition of the pavement. In other words, some of the techniques that were investigated

in this experiment that did not prove successful, might have shown better performance if the pavement had not deteriorated to the extent that it had prior to establishing the experiment. Doubtless, if the pavement had been only slightly in distress, some of the techniques investigated could have acted as "preventative maintenance" and the effectiveness of some of the techniques would have been even better.

Some of the techniques that were investigated were strikingly more effective than others as will be discussed in subsequent paragraphs. On the other hand some of the techniques did not perform well in preventing further deterioration of the pavement.

Summary of Performance

A discussion of the evaluation of the various maintenance methods for this test pavement are given in the previous section of this report. The summary which follows is given in order of most effective to least effective in preventing further deterioration of the pavement irrespective of cost. The reader is referred to previous paragraphs (particularly Table 11) where the cost effectiveness of each of the methods are discussed.

1. Underseal and overlay. These sections have performed very well and no additional failures have

occurred. Table 4 shows that no failures have occurred in this test section and Table 11 shows the cost of the maintenance ($1,511 per 100 feet).

2. Asphalt overlay alone. The asphalt overlay sections have also performed very well and no difference has been found in the performance of overlay relative to the thickness of the overlay itself. This latter point is illustrated in Figure 6 which shows deflection of the various overlay sections with time. Deflection data suggest that these test sections are stabilizing and, in fact, reduced deflection is shown (see also Table 7).
3. Overlay and subdrains. Again the pavements with overlay have shown excellent performance and the data do not suggest that the installation of subdrains along with the overlay has aided substantially in the performance of the pavement.
4. Undersealing. Performance of the underseal sections (without an overlay) has been satisfactory. Three failures have been found in the underseal sections, but it is pointed out that these have occurred at locations that were not actually undersealed. In these test sections, undersealing was only done where the deflection was greater than 0.9 mils (10^{-3} inches). Failures have occurred where the deflection was less than 0.9 mils and consequently

where no undersealing was actually performed at these specific locations. According to data of Table 11 the undersealing has cost just $311 per 100 feet.

5. Bituminous patches. Numerous bituminous patches were placed on the test pavements and no failures have been found associated with these patches. The large bituminous patch at Station No. 1200 + 50 in the southbound lane has shown no distress.
6. Concrete patching only (control sections). The control sections showed various degrees of failure and have demonstrated the effectiveness of the above methods.
7. Subdrains. Numerous failures have occurred on the sections in which subdrains were installed. The subdrains are removing some water from under the pavement. However, the numerous failures that have occurred within these sections suggest that additional work should be done to determine the best means of draining pavements of this type that are in service.
8. Concrete shoulders. The concrete shoulder sections have not performed well and the deflection measurements suggest that continued pavement distress

may be associated with these test sections. One test section included a keyway at the pavement edge whereas the remainder did not. The keyed section of concrete shoulder has performed very well, whereas the non-keyed sections have not.

Summary Discussion

The overlay sections have performed by far the best of any of the maintenance methods used. To date, there is no apparent difference in the performance of the two inch overlay as compared to the five inch overlay although this may change with time. It is highly recommended that the overlay sections be observed further to determine whether this remains to be true over an extended period of time.

Undersealing appears to be an effective means of preventative maintenance. It is known that voids have existed under this pavement and undersealing has corrected this deficiency. Nevertheless, these sections should also be observed further to determine this condition after a longer period of time.

RECOMMENDATIONS FOR FUTURE STUDY

A primary recommendation is made that surveillance of the test pavements should be maintained over a period of two or three additional years. This is particularly important with relation to observing the performance of the various thicknesses of overlay. It is believed that it is too early to make definitive statements relative to the performance of the various thicknesses of overlay and additional data should be obtained on this.

The data suggest that progression of failures in this pavement has slowed down but this cannot be stated with certainty. Therefore to gain the greatest amount of information, performance surveys should be made of the CRC pavements in Indiana to determine the rate of progression of distress.

It is recommended that additional work be done on methods of installing subdrains for removing water under existing CRC pavements. The use of mini-drains appears to be a viable alternative and perhaps the use of fabric around the subdrains should be investigated.

Due to the continuing need for repairing failures, more research should be initiated to investigate methods to improve the construction of concrete patches. The bituminous patches on this project have performed very well, and research should be conducted to determine the feasibility of using bituminous patches instead of concrete patches.

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REFERENCES

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The following Appendices listed in the Table of Contents of this Report have not been included in this copy of the Report:

Appendix	Title	Pages
A	Physical Test Data on Subbase and Subgrade Samples	72-76
B	Number of Failures in Test Sections and Approximate Dates of Occurrence	77-91
C	Deflection of Test Sections at Various Times	92-107
D	Deflection of Pavements with Concrete Shoulder	108-111
E	Typical Deflection Data Taken at Failures and Patches	112-121
F	Cost Data	122-150

A recipient of the Report may receive a copy of the Appendix desired upon request to:

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